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Carbon Nanotubes as Solid Lubricant Additives for Anti-wear Performance Enhancement under Mixed Lubrication Conditions

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ABSTRACT: *The working conditions in many industrial applications cause the tribo pair to operate in the mixed lubrication regime. Since the lubricant film thickness under these conditions is insufficient to separate the sliding tribo pair, therefore usage of lubricant with anti-wear additives is essential. The carbon nano-tubes (CNT) have recently emerged as lubricant additive having extraordinary tribological properties. In the present work, experiments have been conducted on block and disk test setup to determine the effect of using CNT as anti-wear additive in a commercial lubricant. Varying quantities of the CNT have been tried in the lubricant to conduct the wear tests. The wear of the block is quantified in terms of its weight loss after the test. The results of the wear tests are reported.*

Keywords: *Anti-wear additives, Solid Lubricant Additives, Carbon Nano-tubes, Wear, Mixed Lubrication*

I. INTRODUCTION

There are many applications in which the operating conditions, such as heavy load and slow speed, causes the tribo system to operate under mixed lubrication [1]. The contacting surfaces slide over each other resulting in increased friction and wear. Even though many other alternative technologies have been suggested to separate the contacting surfaces [2–17], but the use of solid lubricant additives are cost effective under these conditions as they form a protective and sacrificial layer on the contacting surfaces and thus reduce the friction as well as wear. There are many solid lubricants like Zinc [18], Molybdenum Disulphide [19–21], Tungsten Disulphide etc which are being used as additives in lubricants for minimizing the friction and wear of contacting tribo pairs. However, the modification of graphene sheets in form of seamless tubes called carbon nanotubes (CNT) are found to have very extraordinary tribological properties, but its application as lubrication additive have not become common so far due to the lack of sufficient theoretical justification and corresponding experimental validation of its superior tribological properties. The early work reported by Dresselhaus et al [22] shows that the carbon nano-tubes behave like rolled-up cylinders of graphene sheets of sp^2 bonded carbon atoms. Most of the unusual properties of carbon nano-tubes are a direct consequence of their 1D quantum behavior and symmetry properties, including their unique conduction properties [23]. Popov [24] extensively studied the theoretical aspects directed towards the understanding of the amazing mechanical, electronic, transport, vibrational, thermal, etc., properties of carbon nano-tubes CNT, attributing their uniqueness to the quasi-one-dimensional sp^2-bonded structure of the carbon nano-tubes CNT. Chen at al [25] have studied the tribological properties of carbon nano-tubes CNT and showed the enhancement in tribological properties of a lubricant. A recent study by Zhang et al [26] outlines the recent advances on the utilization of CNTs in tribology with the emphases on anti-friction, wear-proof and self-lubrication. Vaisman et al [27] studied different approaches to decrease the nano-tube agglomeration, namely ultrasonication, high shear mixing, and methods, which are aimed to alter the surface chemistry of the tubes either covalently (functionalization) or non-covalently (adsorption). Their conclusion is that the behavior of surfactants in dispersing the carbon nano-tubes CNT is similar to that of dispersing solid particles. Yang et al [28] showed that the viscosity of nano-tube dispersions is affected by the size of agglomerates in the dispersions. Large agglomerate size leads to dispersions with high viscosity. Rastogi et al [29] recommended the surfactant quantity for Tween 20, SDS, Tween 80, and Triton X-100 surfactants for which the nano-tubes dispersion was found to be highest. The lubricant with properly dispersed carbon nano-tubes CNT is very effective in minimizing wear. The quantity of CNT as solid lubricant additive used by different researchers is in the range of 0.01% to 0.1% by weight of lubricant. Since the CNT fills the surface valleys and provides a smoother surface that prevents wear, the optimum quantity of CNT is dependent on the nature of the contacting surfaces and this requires experimental validation. Therefore there is a need to explore the tribological properties of CNT by conducting experiments. In the present work experimental investigations have been carried out to determine a suitable quantity of CNT which causes the minimum wear of the contacting surfaces that are operating under mixed lubrication conditions. The experiments have been conducted on block and disc test setup to determine the wear of the block in terms of its weight loss. The load and speed combination resulting in mixed lubrication regime has been used. The experimental results are reported.

II. EXPERIMENTAL DETAILS

The experiments have been conducted on block and disk test setup as shown in Fig. 1. The schematic diagram is shown in Fig. 2.

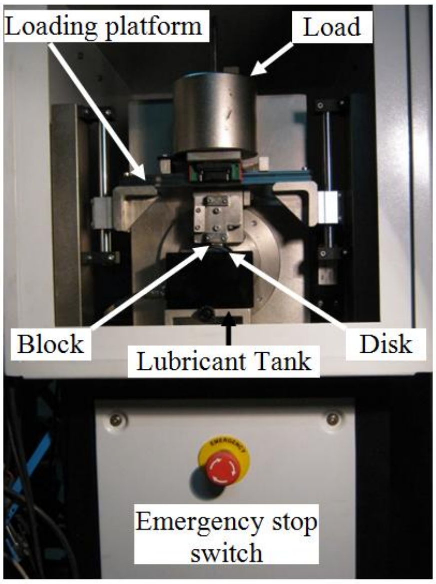

Figure 1 Photograph of block and disk test setup [30]

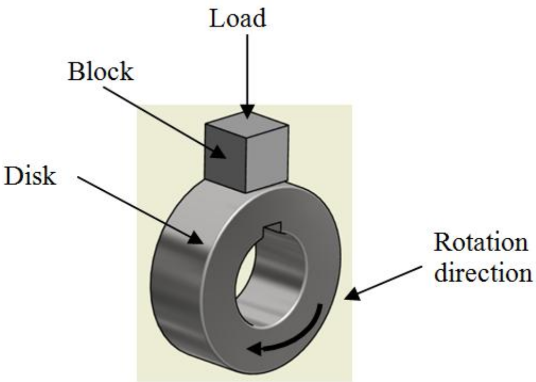

Figure 2 Schematic diagram of block and disk test setup

The block is made of phosphorus bronze material and the disk is made of hardened steel. The disk is of 40 mm diameter and width of 15mm. It is driven by an induction motor. The block is fixed in a holder that is attached to the loading platform. The static load is applied on the loading platform that causes the contact between the flat face of the block with the disk. The flat face of the block slides against the disk. The disk is partially immersed in the lubricant which is maintained at a temperature of 70°C by the help of heaters and a thermal cut-off switch. A combination of a load of 70 N and a sliding speed of 0.05 m/s corresponding to 25 rpm of the disk were considered for the test operating conditions that causes the operation in the mixed lubrication regime. All the tests were conducted for one hour duration.

The lubricant samples were prepared by dispersing the carbon nano-tubes (CNT) in a commercial lubricant with TX-100 as a surfactant by ultrasonic homogenization for duration of one hour. Three lubricant samples were prepared with 0.01%, 0.05% and 0.1% (quantity by weight) of CNT.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The Fig. 3 shows the result of the wear tests conducted on block and disk test setup at the operating conditions mentioned in the previous section.

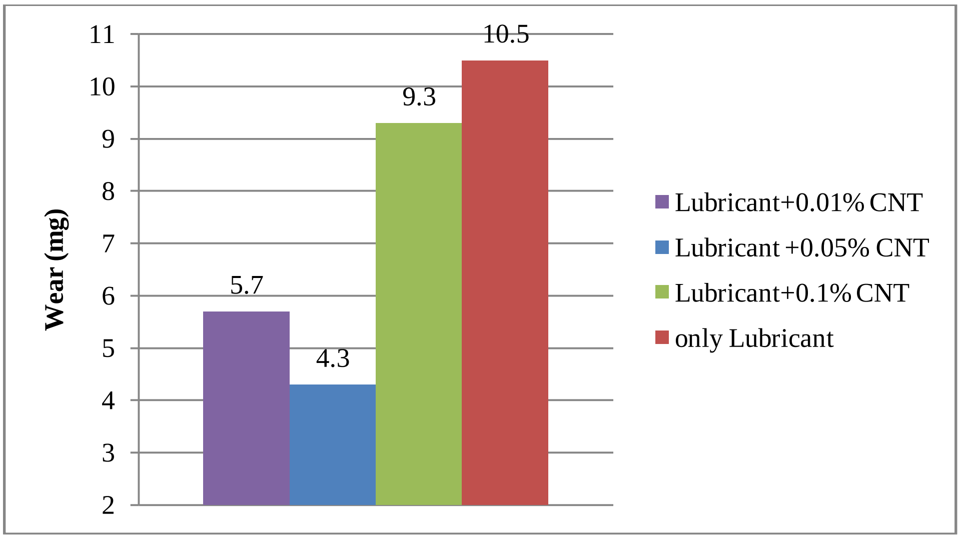

Figure 3 Experimental results

It is observed from the Fig. 3 that there is substantial decrease in the wear of the block when CNT is used as solid lubricant additive. The minimum wear is observed at the 0.05% (weight percentage) of CNT. However a higher wear was observed when the CNT quantity is 0.01% as compared to 0.05% quantity of CNT as well as when the CNT quantity is 0.1%. These observations indicate a certain percentage of CNT provides the minimum wear rate. The estimation of the desired percent of CNT for various operating conditions requires exhaustive experimental investigations. There is a need to perform molecular dynamic simulation of lubricating oil containing the CNT to determine the optimum quantity of the CNT in the lubricant. Since the CNT fills the valleys of the surface and forms protective and sacrificial layer on the surface, therefore the surface topography affects must be incorporated in simulation study. The optimum quantity of CNT as anti-wear additive is thus dependent upon the nature of contacting surfaces and the operating conditions, and there is a need to develop complex computer dynamic simulation algorithm.

IV. CONCLUSION

Based on the observations of the experimental studies, following conclusions are drawn:

- The wear of the sliding surfaces operating in mixed lubrication conditions is reduced by using carbon nano-tubes (CNT) as solid additive in the mineral oil.
- The minimum wear is observed for certain percentage of carbon nano-tubes (CNT) quantity. In the present study 0.05% by weight of carbon nano-tubes (CNT) provides the minimum wear rate.
- Further theoretical and experimental studies are required to establish the optimum carbon nano-tubes (CNT) quantity under varying surface and operating conditions.

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